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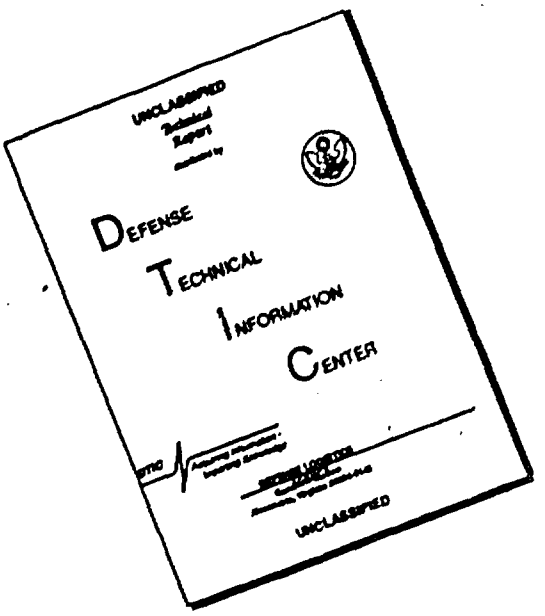

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TECHNICAL MEMORANDUM ASRCE TM-63-16

THERMOPHYSICAL PROPERTIES OF SOME CANDIDATE SUPERORBITAL HEAT SHIELD AND INSULATION MATERIALS

Prepared By

Materials Applications Division
AF Materials Laboratory
Deputy Cmdr/Research & Engineering

6 June 1963

Task 738103

Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

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AF-WP-B-AUG 63 300

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Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

Technical Memorandum
ASRCE TM-63-16

Materials Applications Division
Air Force Materials Laboratory
Deputy Cmdr/Research & Engineering

THERMOPHYSICAL PROPERTIES OF SOME CANDIDATE SUPERORBITAL HEAT SHIELD AND INSULATION MATERIALS

I. PURPOSE:

The purpose of this memorandum is to present a concise summary of the most useful thermophysical properties of some candidate heat shield materials for the thermal protection of superorbital lift reentry vehicles.

II. FACTUAL DATA

1. The following materials properties reports and compendia were searched for pertinent data:

(a) WADC TR58-476
(b) ASD TR62-215
(c) TPRC Data Book Vol. 1, 2, & 3
(d) DMIC Memo 141
(e) WADC TR57-476
(f) ASD TR62-765
(g) DMIC Memo 177

III. CONCLUSIONS

1. The data sheets (Appendix I) constitute Information Processing Section's first compilation in this specific area, and it is intended to be the most complete summary of the data in published unclassified reports and data compendia.

2. In evaluating the reliability of the data, we suggest that the source reference be noted and that they have the following order, the most reliable first:

(a) TPRC Data Book
(b) DMIC Memo 141 & 177
(c) ASD & WADC Technical Reports

3. The emissivity data, while the best available, is probably the least reliable of the data presented.

IV. RECOMMENDATIONS:

It is recommended that this initial review be continued and updated as may be warranted by the availability of new and/or more refined data.

COORDINATION:

Edward Dugger, ASRCE-31

[redacted]

PREPARED BY:

John H. Charlesworth, ASRCE-31

PUBLICATION REVIEW

This report has been reviewed and is approved.

D. A. SHINN
Chief, Materials Information Branch
Materials Application Division
AF Materials Laboratory

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THERMOPHYSICAL PROPERTIES - SUPERORBITAL HEAT SHIELD & INSULATION MATERIALS

Ref.	Material	Density #/ft³	Condition	M. P.	Thermal Conductivity Watts/cm °K	K BTU/hr ft °F @	Temp	Electrical Resistivity	Emissivity @	Temp	Specific Heat BTU/#-°F @	Temp	Linear Thermal Expansion @ % 0.0852OR	Temp.
WADC TR58-476 Vol. I	Graphite gr GBH	109				35.0 16.0	2000°R ⊥ 5000°R ⊥		0.85(0.66) 0.79	2000°R 3500°R	0.54 0.76	4000°R 7000°R		
" "	Carbon (most probable) per reference	140		7100°R										
" "	Graphite Acheson Type 7087	101.7	Extruded Multi-crystalline			46.0 20.0	3500°R ∥ 3500°R ⊥	0.001 Ω cm @ 6000R			0.5 0.75	5000°R 7000°R	1.08 0.85 2.20	4000°R ⊥ 4000°R ∥ 7000°R
" "	Graphite Acheson Type [illegible]		Extruded Multi-crystalline			33 14	1500°R 5000°R	0.001 Ω cm @ 6000°R	0.79 0.70	2000°R 3500°R			0.80 0.57 2.00	4000°R ⊥ 4000°R ∥ 7000°R ⊥
" "	Graphite Acheson Type 547A0	104	Extruded Multi-crystalline			70 2	1000°R 7000°R	0.001 Ω cm @ 6000°R	0.75	1000°R			0.97 0.58 2.30	4000R ⊥ 4000R ∥ 7000R ⊥
ASD TDR62-215	Pyrolytic Graphite	112.5 to 138.5		6600°R	1.5 ("c") 0.1 (dir)	220 ("a") BTU/ 58 (dir) hr ft °F	800°R 4800°R		0.68 0.94	850R 4000R	0.023 0.05	500R 2450R	2.7 (°C°) (dir)	2450R
TPRC DB-Vol. 3	Graphite [illegible]	99.6			0.391 Watts/ 0.455 cm °K		1969.3°K 1049.8°K							
" "	Graphite Type 5474	100.6			0.774 0.567		1980.8°K 1808.7°K							
" "	Graphite Acheson				0.201 0.142		1798.2K 3048.2K	[illegible] Ω cm @ 0 °C						
" "	Carbon (Pure filament)				0.084 0.088		1100K 2100K							
DMIC [illegible]	Columbium	0.310 #/in³	R. T.	4475°F		[illegible]	3100°F		0.41 Total Hemispherical 0.58 (Sandblast)	1500°F 2800°F				
" "	Tantalum	0.600 #/in³	R. T.	5425°F	0.538e 0.450e	50	2425Re 4200°F 5148°Re		0.29 T. Hemi 0.31 (Polished)	3600°F 5200°F	0.067	5200R	0.0 2.5	60°F 5000°F
" "	Chromium	0.260 #/in³	R. T.	3450F	0.600e	39	1273.2Ke 1700F		0.09 (Total Normal) 0.45 (Oxidized)	600°F 1800°F				
" "	Molybdenum	0.369 #/in³	R. T.	4730F	0.885e	42	2795Fe 3400F		0.28 (Total Hemi) 0.28 (Hemi Polished)	3800°F 4600°F	0.135	2800R	0.0 2.0	60°F 4500°F
" "	Tungsten	0.697 #/in³	R. T.	6170F	1.351e	60	3451Ke 2800F		0.28 (Total Hemi) 0.32 (Polished)	3600°F 6000°F	0.035 (1) 0.35 (1)	5000°F (1) 1000°F (1)		
" "	Vanadium	0.220 #/in³	R. T.	3450F		21	900°F							
WADC TR57-467	Hastelloy B Hastelloy C Stellite 21 S.S. 17-7PH S.S. 446					15.1 17.2 20.7 19.8 20.8	1915F 1967F 1980F 1807F 2029F				0.155 0.169 0.179 0.155 0.197	2200°F 2200°F 2200°F 2200°F 2200°F		
WADC TR58-476, Vol. III	Alumina Al_2O_3	250 #/ft³		4160R	0.0640e	9.5 4.5	1000R 1987.2Ke 4500R		Total Normal 0.72 0.44	1000R 4000R	0.26 0.33	1000°R 3500°R	0.0 1.5	520R 3250R
" "	Beryllium Oxide BeO	[illegible] #/ft³		5000R	0.1[illegible]e	76.5 9.0	1000R 4750R 2073.2Ke		0.80 Total	2800R	0.5 (1) 0.5	3500°F (1) 2000°R	0.0 1.95	520R 4000R
" "	Calcium Oxide CaO	207 #/ft³		5120R		4.1	2500R @ 170 #/ft³				0.24	2150°R	0.0 2.25	520R 1760R
" "	Cerium Oxide CeO_2	441 #/ft³		5550R		0.575 (1) 0.670 (1)	2000F (1) 3700F (1)		0.30	2000R	0.1 (1) 0.14 (1)	500F (1) 1500F (1)	0.0 0.52	520R 1500R
" "	Dysprosium Oxide Dy_2O_3	488 #/ft³		4700R									0.0 0.66	520R 2000R
" "	Europium Oxide Eu_2O_3	463 #/ft³		4180R									0.0 0.86	520R 2000R
" "	Gadolinium Oxide Gd_2O_3	477 #/ft³		4720R							0.077 0.075	1000°R 2500°R	0.0 1.70	520R 2250R
" "	Lanthanum Oxide La_2O_3	406 #/ft³		4470R							0.0985 0.100	1000°R 2290°R	0.0 0.72	520R 1750R
" "	Samarium Oxide Sm_2O_3	460#/ft³		4720R							0.38	2000°R		
" "	Magnesium Oxide MgO	295 #/ft³	Polycrystalline	5800R	0.0666e	12.5 5.5	1000R 3750R 2017.2Ke		0.66 Total 0.31 Normal	1000R 3250R	0.30 (1) 0.54 (1)	500F (1) 600F (1)	0.0 2.35	520R 3250R
ASD TDR62-2?5	Molybdenum Disilicide $MoSi_2$	389 #/ft³		3530F		23.0 17.0	1100R 2000R				0.105 0.13	600R 2000R	0.0 1.38	520R 3200R

Figures indicated by asterisk from TPRC
Figures indicated by (1) from TR62-765
Symbols: ⊥ measured perpendicular to processing (molding, extruding, etc.)
Symbols: ∥ measured parallel to direction of processing (molding, extruding, etc.)

THERMOPHYSICAL PROPERTIES - SUPERORBITAL HEAT SHIELD & INSULATION MATERIALS

Ref.	Material	Density #/ft³	Condition	M. P.	Thermal Conductivity Watts/cm °K	K BTU/hr ft °F	Temp.	Electrical Resistivity	Emissivity	Temp	Specific Heat BTU/#°F	Temp	Linear Thermal Expansion % – 0.0652R	Temp
WADC TR58-476 Vol. III	Hafnium Oxide HfO_2	604 #/ft³		5780R		0.95 0.90	1000R 2000R		0.85(1) 0.85(1)	1500F(1) 4000F(1)	0.07(1) 0.13(1)	500F(1) 4750F(1)	0.0 1.32	520R 5000R
" "	Thorium Oxide ThO_2	684 #/ft³		6570R	0.0209*	8.7 2.0	1473.2K* 500R 2000R		0.59 Total 0.42 Normal	1250R 2000R	0.07(1) 0.08(1)	500F(1) 3500F(1)	0.0 1.50	520R 3250R
" "	Uranium Dioxide UO_2	684.0 #/ft³		5670R	0.0145*	2.8 0.6	1000R 1941.1K* 3500R				0.070 0.078	1000R 2500R	0.0 1.30	520R 2500R
" "	Zirconium Oxide ZrO_2	360 #/ft³		5370R	0.0209*	1.0 1.24	1000R 1673.2K* 3000F				0.134 0.144	1000R 3500R	6.1x10⁻⁶/°F(1)	70 to 3500F(1)
" " Vol. IV	Chromium Carbide Cr_3C_2	417 #/ft³		3890R							0.168 0.210	1000R 2250R		
" "	Hafnium Carbide HfC	790 #/ft³		7500R		9.2(1) 17.5(1)	1800F(1) 4600F(1)		0.99(1) 0.85(1)	1500F(1) 4500F(1)				
" "	Molybdenum Carbide Mo_2C	573 #/ft³		5350R					0.67(1) 0.20(1)	900F(1) 4000F(1)	0.085(1) 0.125(1)	500F(1) 3500F(1)	0.0 0.76 0.45	520R 2250R°c° axis// 2250R°a° axis//
" "	Tantalum Carbide TaC	900 #/ft³		7400R					0.40(1) 0.25(1)	1000F(1) 5000F(1)			0.0 0.90	520R 3000R
" "	Titanium Carbide TiC	307 #/ft³		6100R	0.0418*	10.0 2.5	1000R 1355.2K* 2500R		0.6(1) 0.4(1)	1000F(1) 4700F(1)	0.184 0.22	1000R 3250R	0.0 1.28	520R 3000°R
" "	Tungsten Carbide WC	975.8 #/ft³		5690R		25.0(1) 31.7(1)	1500F(1) 4000F(1)		0.6(1) 0.4(1)	1000F(1) 4700F(1)	0.055(1) 0.080(1)	500F(1) 4000F(1)	0.0 0.70	520R 3000°R
" "	Uranium Carbide U_2C_3	795 #/ft³		4760R		20.0	600R							
ASD-TDR62-765	Vanadium Carbide	5.42 gm/cm³				21.6 28.5	1500F 3500F		0.65 0.75	1500°F 4700F	0.190 0.35	500F 4000F	4.10x10⁻⁶/°F	0-3500F
WADC TR58-476, Vol. IV	Zirconium Boride ZrB_2	380 #/ft³		6000R		7.5 16.0(1)	520R 3500F(1)		0.4(1) 0.45(1)	1000F(1) 5000F(1)			0.0 1.0	520R 3000R
WADC TR58-476 Vol. IV	Zirconium Carbide ZrC	400 #/ft³		6840R					0.45 Total(2) Normal	4800F(2)			0.0 0.80	520R 2750R
" "	Hafnium Boride HfB_2	700 #/ft³		6350R		41.7(1) 43.0(1)	1900F(1) 3800F(1)		0.4(1) 0.7(1)	1900F(1) 4800F(1)	0.086(1) 0.120(1)	1300F(1) 4800F(1)	4.5x10⁻⁶/°F	Range 0-4000F
" "	Molybdenum Boride MoB_2	490 #/ft³		4270R										
" "	Niobium Boride NbB_2	440 #/ft³		5940R										
" "	Tantalum Boride TaB_2	787 #/ft³		6800R										
ASD TDR62-765	Tungsten Boride	15.2 g/cm³				28.4 23.4	1900F 4000F		0.5 0.5	1000F 4800F	0.06 0.10	500F 4000F	4.3x10⁻⁶/°F	0-4300F
WADC TR58-476 Vol. IV	Vanadium Boride VB_2	380 #/ft³		4810R										
" "	Titanium Nitride TiN	338(3) 330 #/ft³		5340R(3) 5800R	0.0688*	11.0 5.8	1000R 3500R 1355 2K*	ρ 60x10⁻⁶ Ω cm 1075R	0.45(1) 0.30(1)	1000F(1) 4800F(1)	0.145 0.27	550R 3250R		
" "	Uranium Nitride UN	895 #/ft³		5680R		2.95	980R							
" "	Zirconium Nitride ZrN	442 #/ft³		5150R	0.0558*	6.7 5.3	1000R 1341.2*K 2900R				0.095 0.135	550R 3000R	0.0 0.46	520R 1750R
ASD-TDR62-765	Tantalum Nitride	13.4 gm/cm³							0.70 0.68	1000F 4000F	0.05 0.09	500F 4000F	2.4x10⁻⁶/°F	0-3000F
ASD-TDR62-815	Beryllium Carbide Be_2C			3810F		0.85	1200R				0.75	[illegible]		
" "	Boron Carbide B_4C	156 #/ft³		4440F	14 8	750R 2000R					0.295	550R	0.0 1.5	520R 4100R
" "	Silicon Carbide SiC	201 #/ft³		4710F	8	3800R			0.83 Total Normal	400- 3200R	0.36	[illegible]	0.0 3.8	520R 1900R
" "	Boron Nitride BN	137 #/ft³		5430F		16 7	2400R ǁ 2400R ⊥		0.43 Total Normal	4500R	0.37(1) 0.44(1)	500F(1) 4000F(1)		520R 3000R
	Al_2O_3-Cr_2O_3 System	198 to 250 #ft³		> 3710F		Randomness to 5.5	2100R						0 0.425	520R 2000R
" "	Forsterite MgO-SiO_2	205.8 #/ft³		3455F		3.5 1.70	800R 2050R						.75	1800R
" "	ZrO_2-SiO_2	284 #/ft³		4350		2.5 1.9	1800R 3000R				0.16 0.18	520R 1800R	0.0 0.75	520R 2800R

Figures indicated by asterisk from TPRC.
Figures indicated by (1) from TR62-765
Figures indicated by (2) from DMIC Report 177
Figures indicated by (3) from ASD TR62-815